CONGRESSIONAL BUDGET OFFICE
U.S. CONGRESS
WASHINGTON, DC 20515

Dan L. Crippen
Director

January 31, 2002

Honorable Thomas A. Daschle
Majority Leader
United States Senate
Washington, D.C. 20510

Dear Mr. Leader:

In response to your request, the Congressional Budget Office (CBO) has estimated the potential costs of several different types of national missile defense systems and components:

- the two-site ground-based midcourse system planned by the Clinton Administration;
- a third ground-based site in addition to the two planned in that program;
- an additional ground-based X-band (very high resolution) radar;
- a stand-alone sea-based midcourse system;
- a ship-based X-band radar; and
- a constellation of space-based lasers.

The cost estimates that CBO has prepared for individual systems should not be added together to yield an estimate of the total potential costs of national missile defense. For example, the sum of the estimates for the ground- and sea-based midcourse missile defense systems does not reflect the costs of a single combined system. If they were part of a combined system, the ground- and sea-based systems could draw on some of the same research and development activities and share some of the same sensors, command and control facilities, and components. In addition, as you requested, CBO's assumptions about the architecture and components of the sea-based system reflect its use as a stand-alone system, not as an adjunct to a ground-based system. Finally, in many cases substantial uncertainty exists about the relationship between the system descriptions available to CBO and whatever missile defenses might ultimately be deployed as a result of the programs being planned by the Bush Administration.

Although they involve many of the same elements, the estimates in the attachment to this letter are not directly comparable to those provided by CBO in its April 2000 paper, *The Budgetary and Technical Implications of the Administration's Plan for National Missile Defense.* Among other changes, CBO's current estimate for the ground-based system that would intercept missiles in midcourse now includes the costs of a planned test bed as well as the costs of the Space-Based Infrared System's constellation of satellite sensors to be placed in low-earth orbit (SBIRS-Low).

You requested that CBO prepare an estimate for a sea-based boost-phase missile defense system. Sea-based boost-phase defenses are, however, currently in the very early stages of conceptual development. There are substantial uncertainties regarding the needed capabilities, system architecture, technologies, and schedule for developing and deploying such defenses. The Department of Defense has not yet provided a description of such a system that would be suitable for the purpose of estimating costs. Consequently, CBO was unable to prepare a credible estimate of the costs of sea-based boost-phase defenses.

You also requested an estimate of the costs of the "Brilliant Pebbles" space-based interceptor missile defense system. The most recent complete technical description of that system dates from 1992. Little additional work has been done on space-based interceptors since Brilliant Pebbles was terminated early in the Clinton Administration. Consequently, CBO has no substantive basis for revising its 1996 estimate of the costs for Brilliant Pebbles, and that estimate may no longer be applicable. Although the attachment does not provide estimates for sea-based boost-phase defenses or space-based interceptors such as Brilliant Pebbles, it does identify some of the factors that could ultimately determine the effectiveness and costs of such missile defense systems.

If you wish further information regarding the attached analysis, we would be pleased to provide it. The contacts are Celeste Johnson in the National Security Division, at (202) 226-2900, and Raymond Hall in the Budget Analysis Division, at (202) 226-2840.

Sincerely,

Dan L. Crippen
Director

Enclosure

cc: Honorable Trent Lott
Republican Leader

Identical letter sent to Honorable Kent Conrad and Honorable Carl Levin.

 Attachment

Estimated Costs and Technical Characteristics of Selected National Missile Defense Systems

JANUARY 2002

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FIGURES

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INTRODUCTION AND SUMMARY

In September 2000, President Clinton deferred the decision to deploy a defensive system to protect the United States from a long-range ballistic missile attack. His Administration's national missile defense program was a ground-based system that would eventually consist of two interceptor sites and was designed to defend the United States from a few tens of long-range ballistic missiles by intercepting them in the midcourse of their flights.[1] Citing concerns about technological readiness and the potential reactions of other nations, President Clinton left to his successor the decision of whether or not to move forward with that system or another.

President Bush has signaled his commitment to developing and deploying a missile defense system to protect the United States but has directed a different approach. Instead of continuing to pursue only a limited ground-based midcourse system, the Bush Administration is planning a wide-ranging research and development program for a variety of different missile defense systems. That program will explore systems that would intercept missiles in the boost and terminal phases of their flights as well as in the midcourse phase. Subsequent decisions regarding the architecture of missile defense or the mix of systems to be deployed will be based on the results of that research and development program. The President's fiscal year 2002 budget request included about $7 billion for the Ballistic Missile Defense Organization (BMDO) to conduct missile defense research.[2] It also included $1.3 billion for missile defense programs, such as the Navy Area system and the PAC-3 system, which were proposed for transfer from BMDO to the Navy and Army, respectively—bringing the total request for missile defense to about $8.3 billion. The Congress appropriated $7.8 billion in response. In December 2001, the Department of Defense (DoD) canceled the Navy Area program.

The Congressional Budget Office (CBO) was asked to provide cost estimates for a range of different types (or components) of national missile defense systems, including a two- and three-site ground-based midcourse system; an additional ground-based X-band (very high resolution) radar; a stand-alone sea-based midcourse system; a ship-based X-band radar; a space-based laser (SBL) system; a sea-based boost-phase system; and "Brilliant Pebbles," a space-based interceptor system.

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1. This document frequently refers to the phases of a missile's flight. The boost phase is the period during which the missile's engines are firing, boosting the payload into a ballistic trajectory. The midcourse phase is the period during which a long-range missile is traveling through space—the longest part of its flight. The midcourse phase is sometimes further subdivided into the "ascent" and "descent" phases. At some point during the midcourse phase, the warheads (or other payload) separate from the booster stages of the missile. The terminal phase marks the warheads' reentry into the atmosphere on their way to their targets.

2. The Ballistic Missile Defense Organization's status and name were changed in January 2002. The organization is now an agency within the Department of Defense called the Missile Defense Agency. Throughout this document, the Congressional Budget Office retains the former designation of BMDO.

CBO first addressed the technical characteristics of each of those systems. What elements might constitute the system, and how would they work together to intercept and destroy an enemy missile? When could each of those elements reasonably be expected to be developed and be ready for deployment? Answering those questions was necessary before CBO could address what developing, deploying, and operating those systems would cost. CBO based its analysis on a number of sources, including technical requirements, schedules, and costs for existing programs when those details were available; technical reports from BMDO and other sources; and parametric cost-estimating relationships for missiles, radars, ships, and the other elements of the missile defense systems. CBO did not, however, analyze the potential effectiveness of any of those systems against the threats that they might be designed to counter, except as issues regarding potential effectiveness might affect costs.

The costs of each of the systems considered in this analysis depend on the elements of the system, the technical characteristics and maturity of those elements, and the system's schedule for development and deployment. Currently, the ground-based midcourse system is the most advanced: prototypes of most of its components have been made, and it has undergone several flight tests. The other systems are either in the early phases of technology demonstration, or the concepts for them are under development. For most of the missile defense systems that CBO was asked to consider, no detailed deployment plans or schedules exist. CBO was required to make some assumptions about all three aspects—components, technical capabilities, and schedules—of the systems in order to estimate the costs.

Throughout the body of this document, all estimates are reported in constant 2001 dollars. Estimates that reflect inflation appear in the appendix. The endpoint of the estimates for the ground-based midcourse and the sea-based midcourse systems is 2015, because, on the basis of the schedules that CBO assumes, the 2002-2015 time period would encompass the acquisition period of the systems as well as time for postdeployment operational testing. In the case of ground-based defenses, the most capable, three-site system would reach full operational capability and undergo a period of robust operational testing by 2015. The endpoint for the space-based laser system is 2025, by which time that system would be operational and would have undergone postdeployment testing.

CBO has not provided an estimate of the costs for a sea-based boost-phase system because DoD has released no description, however preliminary, of what might compose such a system. CBO has also not developed a new estimate of the costs of the Brilliant Pebbles space-based interceptor system beyond the estimate the agency did in 1996.[3] The most recent information CBO was able to obtain about that system was a 1992 cost analysis requirements description (CARD). DoD has not done a significant amount of additional work on space-based interceptors since the program was canceled early in the Clinton Administration. Thus, CBO has no basis for revising its previous estimate, which may no longer be applicable. In particular, it is unclear what the relationship might be between the 1992 CARD for Brilliant Pebbles and whatever space-based interceptor system might emerge from the research program that the Bush Administration is beginning.[4]

CBO has provided cost estimates for the ground-based midcourse system with two sites, as envisioned by the Clinton Administration; a third ground-based site; an additional X-band radar based on the ground; a stand-alone sea-based midcourse system; an X-band radar deployed on a ship; and a space-based laser system. While a combined ground- and sea-based system could be built, summing CBO's individual estimates of the ground- and sea-based midcourse systems would not provide accurate costs for such a system because the analysis considers each of those systems in isolation, but some components are common to both systems. In particular, if ground- and sea-based systems were combined, they would probably draw on common research and development and share some components—such as the ground-based sensors and the kill vehicle—resulting in costs that might be somewhat less than if the costs for two stand-alone systems were added together. Moreover, CBO's assumptions about the architecture and components of the sea-based system reflect its use as a stand-alone system. For instance, assumptions about the interceptor's velocity, the patrol locations of the ships—and therefore the number of ships needed, and the number of missiles on each ship are based on the system being stand-alone. If, however, the sea-based system were an adjunct to a ground-based system, it might be designed very differently.

CBO has not examined the whole range of possible configurations for missile defense and how they might be developed and deployed. Many defense experts believe that a combination of different missile defense systems and platforms could defend the United States most effectively. Both limited and more robust architectures for such a layered system are conceivable, deployed in a single step or in multiple, evolutionary steps. Some analysts have suggested, for instance, developing a limited layered defense consisting of a single ground-based midcourse site and a limited boost-phase capability that is either sea-based, ground-based, or airborne, while continuing to conduct research on space-based systems. A more robust system

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3. See Congressional Budget Office, *Budgetary Implications of S. 1635, The Defend America Act of 1996*, CBO Letter Attachment (May 1996).

4. According to the Ballistic Missile Defense Organization, "There are no plans to revitalize or reconstitute the old Brilliant Pebbles program. . . ." Written response from the Ballistic Missile Defense Organization to the Congressional Budget Office, June 29, 2001.

might include multiple ground-based midcourse sites and deployed space-based defenses. Decisions regarding what defenses to deploy and how to deploy them would depend on a number of factors that CBO has not addressed, including the nature and extent of the threat that the United States will face in future years, the potential effectiveness of any missile defense system against such threats, and the potential reactions of allies and other nations to a decision to deploy a missile defense system. Thus, the total costs of national missile defense cannot be determined definitively at this time.

In addition to questions about the structure and goals of a national missile defense system, other factors common to many Department of Defense programs complicate the task of estimating costs. In particular, estimates for systems that are defined only conceptually or that depend on the development of new technologies and the employment of new production methods entail more uncertainty than estimates for well-defined programs based on proven technologies and established production methods. CBO's estimate for the ground-based midcourse system incorporates increases already realized in the costs of developing and manufacturing flight-test interceptors, but CBO has provided a range of costs for the system to account for potential additional cost growth. CBO's estimates for the other systems are also expressed as a range to account for the potential effects on costs of uncertainties and technical difficulties in making the systems fully operational.

Changes in the threat that a national missile defense system is designed to counter may also lead to significant changes in the plans and the consequent costs for any system. For example, some defense analysts argue that enemies could employ certain countermeasures that would significantly decrease the effectiveness of current concepts for missile defense. Should those concerns or others prove true, potentially significant design changes or upgrades might be needed to maintain the system's desired effectiveness, with a concomitant increase in costs relative to estimates for earlier, less effective systems.

A Ground-Based Midcourse System

The Expanded Capability 1 architecture planned by the Clinton Administration would consist of 100 ground-based interceptors deployed at a single site; an X-band radar; five upgraded early-warning radars at various sites; and battle management, command, control, and communications facilities. As the Expanded Capability 1 plan progressed from research and development to deployment over the period from 2002 to 2015, annual costs would vary from less than $1 billion to $4 billion. By 2015, CBO assumes, all the elements of the Expanded Capability 1 architecture would be deployed and fully tested. Through 2015, the costs of this system would total between $23 billion and $25 billion. After that, the continuing costs of operating the system would be about $600 million a year.

Deploying additional radars and sensors—achieving Capability 2 in the Clinton plan—would allow the ground-based system to intercept enemy missiles that employed complex countermeasures, if only a few missiles were launched. To successfully intercept larger numbers of missiles, a Capability 3 system would add a second interceptor site, 150 additional deployed interceptors, more radars, and improved software for each of the system's components. To achieve desired levels of effectiveness, this option would also deploy the Space-Based Infrared System's constellation of satellites in low-earth orbit (SBIRS-Low). The Defense Department claimed that such a system would defend the country against several tens of incoming missiles employing complex countermeasures.

CBO estimates that adding Capability 2 and Capability 3 components would more than double the costs of the ground-based midcourse system. Over the period from 2002 to 2015, as this two-site system moved from research and development to deployment, its annual costs would vary between $2 billion and more than $7 billion, CBO estimates. Through 2015, costs would total between $51 billion and $58 billion. After 2015, annual operating costs would be $1.2 billion.

A third interceptor site consisting of 125 more missiles (for a total of 375 deployed missiles) could be built. As such a three-site system was deployed, annual costs would increase slightly relative to those for the two-site system, varying between just over $2 billion and $8 billion a year over the period from 2008 to 2015. CBO estimates that adding a third site would increase total costs over that period by $5 billion to $6 billion. Through 2015, the three-site system would cost between $56 billion and $64 billion. After 2015, operating costs would be $1.4 billion a year.

A Sea-Based Midcourse System

An alternative approach would be to locate some of the elements of the midcourse system at sea. According to a 1998 BMDO study, a stand-alone sea-based system could be envisioned that might provide protection to the United States roughly comparable to that provided by the ground-based system with a single site.[5] CBO estimates that this stand-alone sea-based system could consist of either seven or nine destroyers, each carrying 35 interceptors, together with the ground-based radars deployed as part of the Expanded Capability 1 system, and the SBIRS-Low space-based sensors deployed as part of Capability 2. According to CBO's estimates, as

5. Ballistic Missile Defense Organization, *Utility of Sea-Based Assets to National Missile Defense* (May 1998). An unclassified summary of the report was released by BMDO in June 1999.

this system progressed from research and development to deployment over the period from 2002 to 2015, its annual costs would vary from $2 billion to $7 billion. Through 2015, CBO estimates, the costs to develop, deploy, and operate the stand-alone sea-based system would total between $43 billion and $55 billion. After 2015, operating costs would be about $1 billion a year.

Boost-Phase Systems

An alternative approach to providing missile defense is to destroy missiles while they are still in their boost phase of flight. A number of concepts for boost-phase national missile defense systems exist, including a constellation of space-based lasers; a constellation of space-based interceptors; and ship-based interceptors or airborne laser systems, both deployed near a threatening country.

A Space-Based Laser System. A space-based laser system would likely consist of a constellation of lasers in low-earth orbit. Using a 1995 SBL cost analysis requirements description as a basis, CBO estimates that the annual costs of a space-based laser system (consisting of a constellation of 24 lasers) would vary from over $1 billion to $7 billion a year over the period from 2013 to 2025, as the operational system moved from development to production and deployment. The total costs to develop, build, and launch that constellation of lasers could range from $56 billion to $68 billion. Those amounts include the costs of a demonstration laser, the Integrated Flight Experiment (IFX), which is planned for launch around 2012.[6] According to CBO's estimates, once it was fully deployed, the space-based laser constellation would cost about $300 million a year to operate, excluding any allowance for ultimately replacing the lasers. Buying and launching replacement lasers would cost $4 billion to $5 billion per year. Such replacements might need to be deployed by 2028, if the lasers were not serviced in orbit to extend their lives.

A Sea-Based Boost-Phase System. There are significant technical challenges associated with developing and deploying an effective sea-based boost-phase national missile defense system. A new interceptor, a new ship, and new sensors might all be required. Current research is focused on investigating the feasibility of this system, the elements of which have not been defined. The costs to deploy a sea-based boost-phase system would depend on the results of that research as well as the number and location of the countries against which such defenses would be employed. At this time, CBO does not have sufficient information about the specific components,

6. In its fiscal year 2002 appropriation bill for the Department of Defense, the Congress awarded only $50 million of the $170 million that was requested for the SBL effort. Such funding will likely curtail research and development activity and could delay the launch date.

development timelines, operational concepts, and capabilities of such a system to develop a credible cost estimate.

The Brilliant Pebbles Space-Based Interceptor System. CBO was also asked to estimate the costs of the Brilliant Pebbles space-based interceptor system. This system's conceptual and technological development began in the 1980s, and it was planned to be part of the first Bush Administration's Global Protection Against Limited Strikes missile defense architecture. But the Brilliant Pebbles program was canceled by the Clinton Administration in 1993. Thus, the technical and operational documentation for Brilliant Pebbles is almost a decade old. Consequently, CBO has no basis for developing a new estimate of the costs for it, and CBO's previous estimate may no longer be applicable.

The current Bush Administration plans to pursue research and development on space-based interceptors. At this point, however, the relationship of the Brilliant Pebbles program to the Bush Administration's plans is not clear.

The remaining sections of the paper describe in more detail each of the missile defense systems that CBO examined and for which it estimated costs.

MIDCOURSE SYSTEMS

Much of the development work done over the past decade on national missile defense systems has been concentrated on a ground-based midcourse system. Midcourse intercept focuses on the longest phase of a missile's flight—lasting about 20 minutes in the case of an intercontinental ballistic missile—and therefore gives the interceptor the greatest amount of time to locate and converge with its target. The missile's location can be predicted from the information gathered during the boost phase of flight, continued observation by radar and sensors, and the mechanics of a ballistic trajectory.

But there are disadvantages to a midcourse system. The chief one is that warheads might be combined with countermeasures—dummy targets to confuse the interceptor. In the airless region of space, the interceptor's sensors may have difficulty distinguishing simple objects employed as countermeasures, such as balloons, from a warhead. And the vast distances covered during the midcourse and the large areas such systems are designed to defend mean that a powerful long-range interceptor missile is required. Notwithstanding those disadvantages, some analysts believe that a midcourse system offers the best opportunity for an early successful deployment.

The endpoint of the estimates for the ground-based midcourse and the sea-based midcourse systems is 2015 because, on the basis of the schedule that CBO assumes, the 2002-2015 time period would encompass the acquisition of the systems and time for deployment and operational testing. In the case of the ground-based system, the time period would be sufficient for the most robust, three-site system.

A Ground-Based System

One of the requests made to CBO was to update the estimates it made in April 2000 for the national missile defense system that was planned by the Clinton Administration.[7] That program called for a ground-based midcourse system to be deployed in three phases of increasing capability (known as Expanded Capability 1, Capability 2, and Capability 3). CBO was also asked to estimate the costs of adding a third ground-based site to supplement the two sites envisioned in the Capability 3 system and to estimate the costs of deploying an additional ground-based X-band radar.

A single ground-based site designed to intercept a few tens of incoming missiles that used simple countermeasures could involve many, if not all, of the same elements as the Clinton Administration's Expanded Capability 1 plan. Similarly, a system involving a second site and designed to deal with more-sophisticated countermeasures would probably include many of the elements from the Capability 2 and Capability 3 plans. Even so, this update of CBO's earlier cost estimates should be used with caution because its underlying assumptions may not directly pertain to whatever ground-based system the Bush Administration may decide to deploy.

As it progressed from research and development to operation over the period from 2002 to 2015, the Expanded Capability 1 plan would have annual costs varying from less than $1 billion to about $4 billion. By 2015, CBO assumes, the elements of this architecture would be deployed and fully tested. From 2002 to 2015, the costs of this system would total between $23 billion and $25 billion, according to CBO's estimate (see Table 1). Those totals exclude over $7 billion appropriated from 1996 to 2001 to develop elements of this system. After 2015, CBO estimates, steady-state operations would cost about $600 million per year.

CBO's estimate of $23 billion to $25 billion includes the costs of developing the system; manufacturing 182 interceptors (100 deployed missiles plus 82 test missiles and spares); constructing an interceptor launch site (planned for Alaska); deploying an X-band radar on the Aleutian island of Shemya; and providing battle management, command, control, and communications facilities. The estimate also

7. See Congressional Budget Office, *Budgetary and Technical Implications of the Administration's Plan for National Missile Defense*, CBO Paper (April 2000).

includes the costs of upgrading the capabilities of existing radars that provide early warning of ballistic missile launches. The system would draw on the Defense Support Program's early-warning satellites and, later, on that program's planned replacement, the Space-Based Infrared System High (SBIRS-High) constellation

TABLE 1. COSTS OF VARIOUS GROUND-BASED NATIONAL MISSILE DEFENSE SYSTEMS, FISCAL YEARS 2002-2015 (In billions of constant 2001 dollars)

	A Single-Site System		A Two-Site System and More Radars/Sensors		A Three-Site System	
Type of Cost	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Research and Development						
Ground-based system	6	7	9	9	9	9
SBIRS-Low	0	0	4	5	4	5
Subtotal	6	7	12	14	12	14
Production						
Ground-based system	8	10	16	18	19	22
SBIRS-Low	0	0	8	11	8	11
Subtotal	8	10	24	29	27	33
Military Construction	1	1	3	3	4	4
Total Acquisition Costs	16	18	39	46	43	51
Operations Through 2015	7	7	12	12	12	12
Total Costs Through 2015	23	25	51	58	56	64
Memorandum:						
Annual Costs for Operations After 2015	0.6	0.6	1.2	1.2	1.4	1.4
Annual Costs to Replace SBIRS-Low Satellites After 2015	0	0	0.8	1.0	0.8	1.0

SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

SBIRS-Low = Space-Based Infrared System in low-earth orbit.

(which will have satellites in geostationary and highly elliptical orbits, as opposed to low-earth orbit). The estimate does not include the costs of any of those satellites, however, because they either exist today or are being developed to fulfill a primary function other than missile defense.

The estimate includes $2 billion for a missile defense test bed consisting of multiple facilities in the Pacific. That test bed, which was not part of the Clinton Administration's plan but which is part of the current Administration's research and development plan, involves upgrades to the existing testing infrastructure; facilities at Kodiak Island, Alaska; and interceptor launch facilities at Fort Greely, Alaska. Later, it is also planned to include an additional prototype X-band radar. According to the Department of Defense, elements of the test bed could provide the nation with a limited missile defense capability as early as 2004.

The Expanded Capability 1 system was intended to defend the entire United States from attack by several tens of ballistic missiles that employed simple countermeasures. But, over time, adversaries could develop more sophisticated countermeasures. To cope with those, the Clinton Administration planned, in Capability 2, to add more radars and sensors to the system. Those additional sensors would allow the system to handle more-sophisticated countermeasures, provided only a few missiles were launched. Therefore, in Capability 3, the Clinton Administration planned for a second interceptor site, 150 additional interceptors, more radars, and improved software. That capability would defend the country against several tens of incoming missiles with sophisticated countermeasures.

Adding that second interceptor site with additional radars and space-based sensors encompasses what the Clinton Administration called Capability 2 and Capability 3. Over the period from 2002-2015, as the two-site system encompassing Capability 2 and Capability 3 moved from research and development through deployment, the annual costs would vary between $2 billion and more than $7 billion, CBO estimates. Costs would total between $51 billion and $58 billion over the 2002-2015 period—or $28 billion to $33 billion more than for the single-site system. The estimate excludes about $9 billion appropriated over the 1996-2001 period to develop ground-based missile defense and SBIRS-Low. CBO assumes that the second site and the additional radars and sensors would be operational by 2011. CBO's estimate includes the costs of building eight additional X-band radars, additional interceptor communications facilities, an additional interceptor site, and 192 additional interceptors (150 of which would be deployed and 42 of which would be used in tests or as spares), as well as the costs of upgrading an additional early-warning radar.

The estimate includes the costs of the Space-Based Infrared System Low, a constellation of 27 satellites in low-earth orbit that would track reentry vehicles and other objects that might accompany them as countermeasures and attempt to discriminate warheads from countermeasures. CBO estimates that the costs to develop, build, launch, and operate SBIRS-Low would total between $13 billion and $16 billion over the 2002-2015 period. Those figures do not include over $1 billion in research and development funding that was appropriated prior to 2002. Operating costs for the two-site system with its radars and sensors would average just over $1 billion per year. The increase relative to the single-site's operating costs reflects the additional expenses to operate the second site, the additional radars, and SBIRS-Low.

The range in the cost estimate reflects the potential for cost growth in several elements of the ground-based system, including SBIRS-Low. Cost uncertainty is greatest for SBIRS-Low because it is at the earliest stages of development. In particular, cost growth in SBIRS-Low is likely because of technical uncertainty about the performance of the satellite system and risk in the program overall. For example, the General Accounting Office concluded in a 2001 report that DoD is pursuing a high-risk schedule for developing and deploying the SBIRS-Low satellites.[8] Although the schedule includes tests of the system with the satellites in orbit, the information from those tests will not be available in time to affect the design and production of those satellites. In addition, the department plans to pursue an evolutionary approach to software development so that the first few satellites will have the software to support only a few of the missions the constellation is planned to perform. But the software to support all of the missions will not be available until three years after the first satellite is launched. Finally, the projected weight of the SBIRS-Low satellites has increased markedly, and the number of satellites needed is still in question.

A third interceptor site with 150 additional interceptors (125 deployed and 25 for tests and spares) and the associated ground infrastructure could be added to the two-site ground-based system. CBO assumes that this third site could be operational in 2012. As this system progressed from research and development through deployment, annual costs for the three-site system would increase slightly relative to those for the two-site system (varying between about $2 billion and $8 billion a year over the 2002-2015 period). Through 2015, CBO estimates, the third site would add $5 billion to $6 billion to the costs of the system. That estimate includes the costs of buying the interceptors, building the site, and integrating the site with the command and control infrastructure. Thus, the three-site system would cost between $56 billion and $64 billion through 2015. After 2015, operating costs for such a system would average about $1.4 billion a year. Figure 1 displays the annual costs over time for the three-site system.

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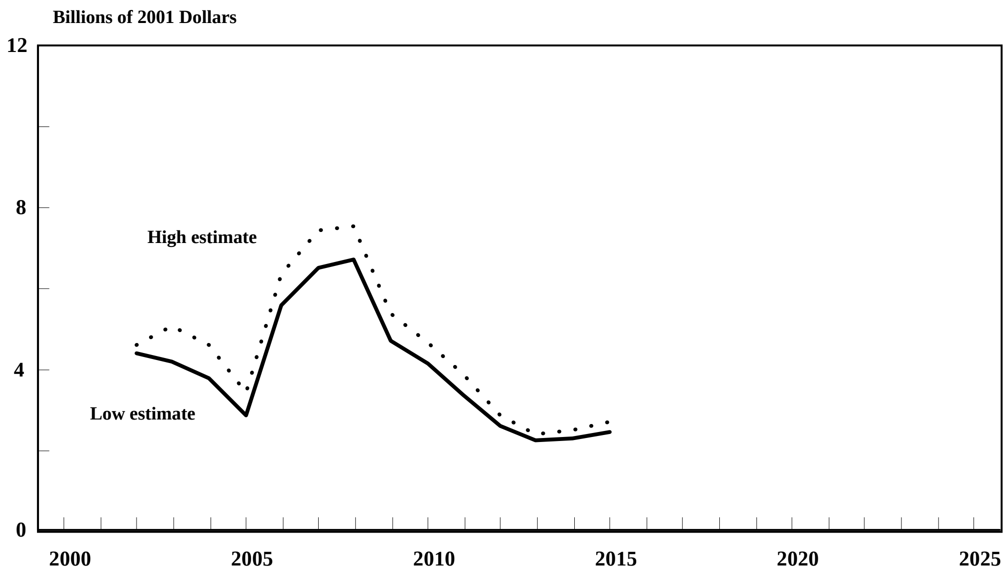
8. General Accounting Office, *Defense Acquisitions: Space-Based Infrared System-Low at Risk of Missing Initial Deployment Date* (February 2001), pp. 3-5.

CBO estimates that the cost to build an additional X-band radar (beyond the nine included in the estimates in Table 1) would total about $500 million and the cost to construct the radar's platform would total about $200 million. In addition, CBO estimates that the operating costs for the radar would total about $20 million a year. CBO assumes that this radar would be located in one of the 48 contiguous United States; if it was located outside that region, those costs might be greater.

Technical uncertainties remain concerning the performance of the ground-based midcourse system, which could lead to cost increases over CBO's estimates. Significant among those uncertainties is the kill vehicle's ability to distinguish enemy warheads from debris or any countermeasures that an adversary might employ. Critics argue that the infrared sensors on the kill vehicle and on the SBIRS-Low satellites might not be capable of distinguishing simple countermeasures from the

FIGURE 1. ANNUAL COSTS FOR A GROUND-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM WITH THREE SITES, FISCAL YEARS 2002-2015



SOURCE: Congressional Budget Office.

NOTES: Total costs through 2015 = $56 billion to $64 billion.

The horizontal axis in this figure spans the period 2002 to 2025. That time period would encompass the development, deployment, and initial operational testing of all of the missile defense systems for which CBO has made cost estimates.

warheads. If those deficiencies turned out to be the case, additional sensor types might need to be added to the system, which would probably increase costs above CBO's estimates.

A Stand-Alone Sea-Based System

CBO was also asked to examine the components, timeline for development and deployment, and costs of a stand-alone sea-based system to defend the nation by intercepting enemy missiles in the midcourse phase of their flights. It was asked to base its analysis on a report that the Ballistic Missile Defense Organization provided to the Congress in June 1999 on the utility of sea-based components for the national missile defense mission. That report is a summary of the classified report that BMDO released in 1998.[9]

BMDO's reports describe a sea-based system that could provide protection to the United States comparable to that planned for the single-site ground-based system. The sea-based system would build on the basic concepts and several of the technologies of the prospective Navy Theater Wide missile defense system (see Box 1).

The system envisioned in BMDO's 1998 and 1999 reports includes a faster, more capable interceptor; a much more capable kill vehicle than that planned for the Navy's theater defense system; and a dedicated new ship with a modified missile launching system. According to BMDO, that stand-alone sea-based system would require the same radars and sensors for tracking and discrimination as those used in a single-site (Expanded Capability 1) ground-based system. It could also require the deployment of SBIRS-Low, because without it, according to the reports, portions of Alaska could not be defended under all scenarios. Effectively, this architecture would take the single-site ground-based system and put the interceptors to sea.

According to CBO's estimates, as this system progressed from research and development through deployment, its annual costs would vary from $2 billion to $7 billion over the 2002-2015 period (see Figure 2). The costs to develop, deploy, and operate this system over that same time period would total between $43 billion and $55 billion, CBO estimates (see Table 2). That estimate does not include the nearly $9 billion in funds appropriated from 1996 to 2001 to develop the ground-based midcourse system and SBIRS-Low, which could also reasonably be considered part

9. See Ballistic Missile Defense Organization, *Summary of Report to Congress on Utility of Sea-Based Assets to National Missile Defense* (June 1999), and Ballistic Missile Defense Organization, *Utility of Sea-Based Assets to National Missile Defense* (May 1998).

BOX 1.
THE NAVY THEATER WIDE SYSTEM

The Navy Theater Wide missile defense system was conceived to protect deployed U.S. and future coalition forces, ports and airfields, vital military and political assets, and population centers around the world. The system, to be deployed on Navy ships equipped with the Aegis combat system, would intercept medium- and long-range theater ballistic missiles in the midcourse of their flights. The Clinton Administration planned to deploy the system in two phases: Block I would provide an initial capability by 2006 and be fully deployed by 2010. A follow-on upgrade, Block II, would provide greater coverage and be able to intercept threats that were more sophisticated.

The Bush Administration has redefined the Navy Theater Wide system as the sea-based component of its research program for midcourse systems, and it is now also referred to as Sea-Based Midcourse. For fiscal year 2002, the Congress appropriated about $3.8 billion for research on midcourse systems, $476 million of which was for developing and testing the Navy Theater Wide/Sea-Based Midcourse system. Future decisions about the direction of the program, its capabilities, and deployment timelines will be deferred pending the results of that development and testing.

of the costs of developing this system. After 2015, operating costs would total about $1 billion a year.

CBO's estimate includes the costs of designing and building a new interceptor with greater speed than the Navy Theater Wide Block II interceptor. On the basis of information from the Ballistic Missile Defense Organization, CBO assumes that the interceptor would carry the same kill vehicle as the one being developed and built for the ground-based system. Because the system is assumed to stand alone, the estimate for the interceptor includes the remaining costs of designing and developing that kill vehicle. Those costs presumably would not be incurred twice, however, if sea-based and ground-based systems were both deployed and were able to use the same type of kill vehicle.[10]

CBO's estimate also includes the costs of constructing either seven or nine new Arleigh Burke class destroyers at a cost of a little over $1 billion a ship. Those costs are included because, according to BMDO's 1998 report, the anticipated patrol locations might not be completely consistent with the Navy's existing missions (see Box 2). According to BMDO, the new ships would be equipped with modified versions of the current missile launching system in order to accommodate the larger, faster interceptor required for the mission of national missile defense. CBO assumes that the ships would also have to be equipped with new communications links to the ground-based sensors and command, control, and communications facilities.

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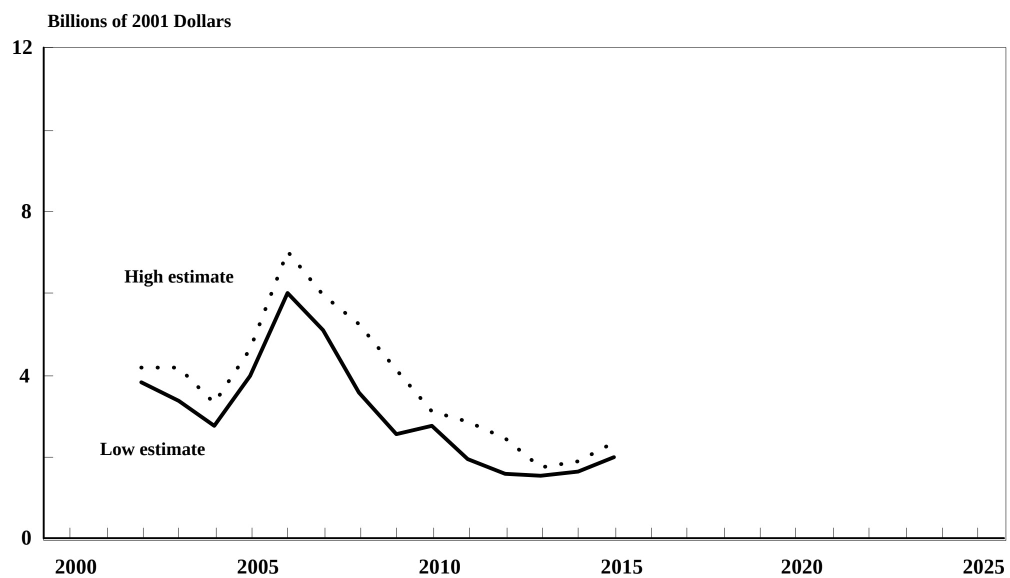
10. CBO has not examined the feasibility of placing this kill vehicle on a ship-based missile, but there could be significant challenges in making such a kill vehicle compatible with shipboard operations.

One major difference between the low end and the high end of CBO's cost estimate is the different number of ships purchased (and the different number of associated interceptors on those ships). The low end represents seven ships and 325 interceptors, and the high end represents nine ships and 395 interceptors. In each case, CBO assumes 35 missiles per ship and 80 additional missiles for use in tests and as spares. CBO has varied the number of ships because the 1998 BMDO report did not provide enough information to calculate the exact number that would be needed. Although that report provided the ships' patrol locations, where the ships would be based was unclear. The basing arrangements, including the sea-shore rotation and maintenance, would be a primary factor in determining how many ships were required. Another major difference between the low estimate and the high estimate is that the high estimate assumes greater production costs for the ships and missiles and includes the costs of the test-bed facility planned for the ground-based system. Finally, the estimate also includes a range of costs for the ground-based radars and SBIRS-Low, as discussed earlier.

FIGURE 2. ANNUAL COSTS FOR A STAND-ALONE SEA-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2015



SOURCE: Congressional Budget Office.

NOTES: Total costs through 2015 = $43 billion to $55 billion.

The horizontal axis in this figure spans the period 2002 to 2025. That time period would encompass the development, deployment, and initial operational testing of all of the missile defense systems for which CBO has made cost estimates.

TABLE 2. COSTS OF A STAND-ALONE SEA-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2015 (In billions of constant 2001 dollars)

Type of Cost	Total Costs: Low Estimate	Total Costs: High Estimate
Research and Development		
Sea-based system[a]	6	9
SBIRS-Low	4	5
Ships	*	*
Subtotal	10	15
Production		
Sea-based system[a]	10	13
SBIRS-Low	8	11
Ships	7	10
Subtotal	26	34
Military Construction	1	1
Total Acquisition Costs	38	50
Operations Through 2015	5	5
Total Costs Through 2015	43	55
Memorandum:		
Annual Costs for Operations After 2015	0.9	1.0
Annual Costs for Replacing SBIRS-Low Satellites After 2015	0.8	1.0

SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

SBIRS-Low = Space-Based Infrared System in low-earth orbit; * = about $500 million.

a. Includes the costs of sea-based interceptors and a ground-based infrastructure.

BOX 2.
THE USE OF NAVY SHIPS FOR NATIONAL MISSILE DEFENSE

The Navy has 27 Ticonderoga class Aegis cruisers in the fleet today, 22 of which are equipped with the vertical launch system that would probably be needed for missile defense. It also has 33 Arleigh Burke class Aegis destroyers. Those ships currently perform a number of missions, including air defense for carrier battle groups, antisubmarine warfare, the enforcement of sanctions, antidrug operations, and attacks on land-based targets with Tomahawk missiles.

The impact of being assigned the national missile defense mission on the Navy's ability to accomplish other missions depends in large measure on the role naval assets would play, that is, what threats the ship-based system would defend against, what territory it would defend, and whether patrols were continuous or not. Dedicating some Aegis ships to the national missile defense mission might reduce their availability to perform current missions, including theater missile defense and battle group command, control, and communications. It might also reduce the number of ships deployed around the world that were available to respond to contingencies.

Development of a stand-alone sea-based system could involve significant technical challenges, which could in turn lead to greater costs than those projected here. Uncertainties include the arrangements for command, control, and communications among the ground-based sensors, other ground-based facilities, and the ship, as well as the technical requirements for development of a sea-based interceptor.

The ground-based system planned by the Clinton Administration included an array of underground cables as well as space-based communications equipment to relay data from the early-warning satellites and the early-warning radars to command and control facilities, which in turn would forward tracking information on the enemy missile to the interceptor facilities and to the interceptors themselves. How this process would take place if the interceptors were on ships on patrol in open waters is unclear. To make up for the lack of underground cables, greater satellite communications capability could be needed. That could, in turn, lead to other technical challenges such as development of systems on the ships that could receive and interpret the data to pass on to the interceptors. Although CBO's estimate includes some costs for the development of those capabilities, that development could prove more difficult—and more expensive—than CBO has assumed.

The Department of Defense has faced a number of challenges in developing the ground-based interceptor—both with the booster and the kill vehicle. The development of a sea-based interceptor could present a new and different set of technical hurdles. The interceptor for national missile defense could be much larger than the missiles currently launched from the vertical launch system (VLS) on surface ships. The department believes that the VLS can be altered to accommodate a larger missile. However, it is possible that alternatives to that system may need to be explored, which could lead to greater costs. Moreover, whether the current ground-based kill vehicle could simply be placed on sea-based interceptors is also unclear. A unique maritime variant may need to be developed.

Sea-Based Components to Supplement a Ground-Based System

As requested, CBO's estimate reflects the costs of a stand-alone sea-based system. BMDO's 1998 and 1999 reports, however, also address ways in which sea-based components could be used to supplement a ground-based system. More recently, BMDO and the Navy have produced a broader analysis of how sea-based components could supplement a ground-based system.[11]

The December 2000 analysis by BMDO and the Navy identifies three potential adjunct roles for sea-based components in the mission of national missile defense. One, a role called "Strategic Missile Trap," would supplement the ground-based system by using ship-based interceptors to provide earlier opportunities to destroy missiles in certain trajectories. To perform such a role, Navy ships could carry interceptors capable of national missile defense. Those ships would not have radars with sufficient range and capability to track long-range threats; rather, they would rely on the ground-based sensor system. A second role, "Strategic Radar Picket," would provide close-range sensor coverage of potentially threatening countries. To perform that role, ships equipped with relatively large and capable X-band radars (but not interceptors) would patrol areas nearer to hostile countries. A third role, "Strategic Defense," would be performed by Strategic Defense Cruisers, which combine faster, more-capable interceptors and X-band radars on a single ship. According to the December 2000 report, that role could be played by existing Ticonderoga-class cruisers backfitted with a radar and equipped with midcourse interceptors. (The X-band radar used in this concept would be significantly smaller and less capable than the radar planned for the ground-based system.) With radars as well as interceptors integrated in a single ship, such a system could play both the Strategic Missile Trap and Strategic Radar Picket roles, supplementing other defenses of the United States (such as ground-based ones). Such a system might also extend that defense to U.S. territories and U.S. allies.

The potential contribution of sea-based components and the trade-offs between sea-based and ground-based systems are under study by the Defense Department. Sea-based options remain largely conceptual, so additional research and development are necessary before an operational system can be defined. The eventual costs of any given sea-based option will depend on many factors, including

11. Ballistic Missile Defense Organization and U.S. Navy, *Naval National Missile Defense: A Potential Expansion of the Land-Based NMD Architecture to Extend Protection* (December 2000).

what the threats are that the system will defend against; what territory it will defend; whether the ships will be on patrol continuously or used only in the event of a crisis; and whether the ships will be dedicated solely to the mission of national missile defense or will be multimission.

Deployment of an X-Band Radar on a Ship

CBO was also asked to estimate the costs of deploying an X-band radar on a ship. According to the recent study by BMDO and the Navy cited above, such radars could make a ground-based national missile defense system more robust. Based near countries that might pose a threat, ship-based radars could improve the system's ability to identify targets by tracking them for a longer period and viewing them from different angles. Those radars would not be replacements for ground-based radars; they would supplement them.

According to the BMDO-Navy study, a ship-based radar designed specifically to extend the ground-based sensor architecture would likely be too big to be accommodated on current Aegis cruisers. On the basis of information obtained from BMDO, CBO estimates that designing and developing the radars and ships to accommodate them could cost from $1 billion to $3 billion. Constructing the radar ships could cost from $1 billion to $2 billion each. The low end of the estimated price ranges assumes a smaller radar that could be installed on a commercial ship without military features. The high end assumes a larger radar and a ship incorporating defenses common on Navy ships.

BOOST-PHASE SYSTEMS

CBO was asked to estimate the costs of a space-based laser system and a sea-based system—both to intercept enemy missiles in the boost phase of their flights. Most boost-phase systems that could defend the United States against long-range missiles are still in the conceptual stage, and the exact requirements for most of them have yet to be fully described. A boost-phase system would operate under a concept different from a midcourse system; whereas a midcourse system would destroy enemy warheads in space after separation from the missile that launched them, a boost-phase system would destroy the missile itself during the relatively short period that it was in powered flight.

The mechanism that a boost-phase system would use to destroy an enemy missile could be a laser that deposited energy on the boosting missile or an interceptor that rammed into the missile.[12] A high-powered laser mounted on a space-based platform would aim its beam at the enemy missile, heat the missile body, and thereby cause structural failure. By contrast, a "hit-to-kill" system would launch an interceptor toward the boosting enemy missile and destroy it by ramming into it at very high speed (using the same kill mechanism as in the midcourse systems discussed earlier).

A boost-phase approach has some advantages over the midcourse approach. The midcourse system has to locate a comparatively cool warhead against the cold background of space. In contrast, a boosting missile gives off a very bright infrared signature, making it comparatively easy to locate. Also, during much of its boost phase, a missile is moving more slowly than its warhead or warheads will move after separation. Attacking the enemy missile while it is boosting also obviates the need to worry about the use of balloons or other countermeasures that adversaries could deploy in the midcourse—often cited by critics as one of the primary problems with midcourse systems.

But a boost-phase system also has a number of disadvantages. The main one is that time is so short. A long-range ballistic missile is in powered flight for only about three to five minutes. Missiles designed to accelerate and burn out quickly would provide even less time for boost-phase defenses to be employed effectively. Consequently, in a hit-to-kill boost-phase system, the interceptors must be very fast. The needed timing could also mean that defensive missiles would need to be launched immediately after an enemy missile was detected, without the opportunity to consult senior leaders. Another disadvantage is that a boost-phase system that damages the missile may not destroy its warheads. If the warheads survived the destruction of the missile boosting them, they could fall short of their intended targets but still inflict damage. Finally, certain countermeasures against some boost-phase systems might be effective. For example, in the case of a directed-energy missile defense system, an adversary might paint the missile with a reflective coating or line it with a heat-absorbing material to thwart the defense.

A Space-Based Laser System

In concept, a space-based laser would intercept an enemy ballistic missile by concentrating its high-energy laser beam on the target, heating it, and thereby causing the missile to break up. In such a system, the lasers would need to be placed in a

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12. This discussion focuses on interceptors that use "hit-to-kill" technology—that is, the interceptor destroys the enemy missile by ramming into it. Including explosives in the interceptor might also be possible, which could mean that the interceptor would need only to get close to the enemy missile, rather than directly hit it. Interceptors incorporating explosive warheads might also be effective elements of a boost-phase system.

low-earth orbit to be within effective range of their intended targets. A constellation composed of many lasers would be needed to improve the chance that missiles launched from a number of locations, at any time, could be intercepted.

The Department of Defense has explored technologies for using a space-based laser for national missile defense since the 1970s. However, most of the work done to date has been focused on developing the concept and its basic technologies. The deployment of an operational SBL system could be at least 15 years away, and considerable uncertainties remain about the viability and maturity of the technologies.

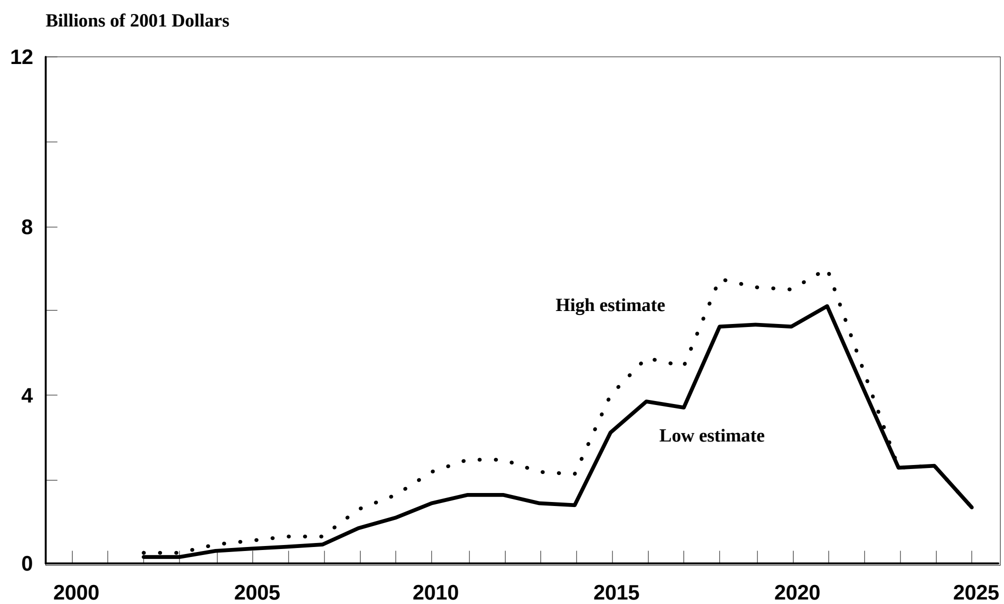
BMDO plans to investigate the feasibility of a space-based laser using the Integrated Flight Experiment project, which is expected to place a single high-energy laser in orbit around 2012. The IFX laser would be smaller and less powerful than the lasers in the deployed SBL system. The results of the IFX project will help determine what the effectiveness and costs of an operational SBL capability would be and whether an acquisition program should be initiated. The Bush Administration requested $170 million in fiscal year 2002 for the SBL project. In response, the Congress provided $50 million in its 2002 defense appropriation bill.

CBO was asked to estimate the costs of developing and deploying a space-based laser system. The eventual costs of an operational SBL capability will depend on a range of choices not yet made, technical outcomes that are uncertain, and the evolution of the threats. In order to provide a cost estimate, CBO has had to rely on documentation made available by DoD and the description of the laser and other components contained in those documents. Contractors and other analysts have conducted recent studies on space-based laser systems, but the most recent complete system description available from DoD dates from 1995. CBO has used that documentation as the basis for developing its estimate, which applies only to the system described by the department. Because of the technical uncertainties and early stage of the system's development, CBO has provided a range estimate for the costs of that system. CBO has also provided a discussion of the uncertainties associated with developing and deploying an operational SBL system. Those uncertainties could have a significant effect on the ultimate costs. For example, if the system ultimately deployed had more lasers or the system was composed of different elements (such as a combination of space-based lasers and space-based mirrors) than the ones in the system described by DoD in 1995, then the costs could be very different—in some cases lower, and in a number of other cases higher.

CBO estimates that the total costs of the Integrated Flight Experiment project would be between $3 billion and $5 billion. CBO assumes that IFX is required in order to demonstrate the technologies needed for an operational SBL; that is, a decision to pursue a full operational space-based laser constellation would be based on the results of IFX. CBO estimates that the annual costs for the development, production, and deployment of an operational SBL would vary from more than $1 billion to $7 billion over the 13-year period from 2013 to 2025 (see Figure 3). The total costs to develop, build, and launch a constellation of 24 lasers could range from $56 billion to $68 billion (see Table 3).

CBO's estimate assumes that the lasers are launched at a rate of three per year beginning in 2018. It includes the costs for designing and testing the laser and a new launch vehicle, the costs to buy the lasers, and the costs to launch them into orbit, and it assumes that one laser could be launched per vehicle. Between the first launch and full operational capability in 2025, CBO estimates, the total costs for operating the lasers would be about $2 billion. Eventually, the 24-laser constellation would cost about $300 million a year to operate, excluding the costs to replace the lasers. The costs of building and launching replacement lasers could range from $4 billion to $5 billion annually, assuming that the lasers would be replaced at a rate of three per year. If the service lives of the lasers were extended, perhaps by servicing in orbit, then the costs might be lower, but the mechanisms for such servicing (and the attendant costs) have not been provided to CBO.

FIGURE 3. ANNUAL COSTS FOR A SPACE-BASED LASER NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2025



SOURCE: Congressional Budget Office.

NOTE: Total costs through 2025 = $56 billion to $68 billion.

One way to place CBO's estimate for SBL satellites in context is to compare it to the production costs of other military satellites, normalized for spacecraft weight On that basis, CBO estimates that SBL satellites would cost from $13,000 to $16,500 per pound of spacecraft weight. Costs for other military satellites now in orbit range from about $17,000 per pound for earlier versions of the Global Positioning System satellites to about $40,000 per pound for Defense Support Program (missile launch warning) satellites. CBO's estimate takes account of the fact that much of SBL

TABLE 3. COSTS OF A SPACE-BASED LASER NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2025 (In billions of constant 2001 dollars)

Type of Cost	Total Costs: Low Estimate	Total Costs: High Estimate
Research and Development		
IFX laser	3	5
Operational laser	7	11
Launch vehicle	3	5
Subtotal	14	20
Production		
Operational laser	27	33
Launch vehicle	13	13
Subtotal	40	46
Total Acquisition Costs	54	67
Operations Through 2025	2	2
Total Costs Through 2025	56	68
Memorandum:		
Annual Costs for Operations After 2025	0.3	0.3
Annual Costs to Replace Space-Based Lasers After 2025	4	5

SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

IFX = Integrated Flight Experiment.

The space-based laser (SBL) system comprises a constellation of 24 lasers.

satellites' weight would be due to relatively simple components such as the tanks containing the lasers' fuel.

Major uncertainties associated with the space-based laser program described by the Defense Department include:

- o The mechanism for launching the lasers into space and

- o The effectiveness of the individual lasers and the resulting size and composition of the space-based laser constellation.

<u>The Mechanism for Launching the Lasers into Space</u>. The Defense Department estimates that an operational laser (of the type currently planned) could weigh about 80,000 pounds. But the United States does not possess a launch vehicle capable of lifting that large a payload into orbit. The next-generation heavy-lift launch vehicle is expected to carry about 50,000 pounds to low-earth orbit. In order to launch a payload of nearly 80,000 pounds, the United States would need to either develop and build a new heavy launcher (as assumed in CBO's cost estimate and in DoD's 1995 documents on the SBL system) or launch the lasers in sections and assemble them in orbit. The technical and engineering challenges associated with the latter concept could be significant. Designing and building a new launch vehicle capable of lifting a nearly 80,000 pound payload into orbit would also be a challenge, though not unprecedented.[13] Although CBO assumes that the existing launch infrastructure would be adequate, new or specialized launch facilities could be needed to use a new heavy launcher and to place the lasers into the correct orbit. If so, costs would increase relative to CBO's estimate.

<u>The Effectiveness of Lasers and the Size and Composition of the Space-Based Laser Constellation</u>. One of the major determinants of the costs of a space-based laser system would be constellation size—the number of lasers needed. That constellation size would be determined by a number of factors, including the lasers' power and brightness, the level of coverage desired, and the vulnerability of the ballistic missile threats against which the system would be designed to defend.

To destroy an enemy missile, a space-based laser must be able to apply enough energy to a specific portion of that missile to cause it to break apart. The amount of energy needed is called the lethal fluence (lethal fluence is a measure of energy applied over a unit area, expressed in thousands of joules per square centimeter). The lethal fluence must also be applied over a relatively short period of time; the wall of the enemy missile must experience a certain minimum intensity of

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13. Variants of the United States' Saturn V launch vehicle could lift as much as 250,000 pounds.

laser energy, measured in watts per square centimeter.[14] The lethal fluence for a given missile depends on the missile's characteristics—how "hard" or "soft" the missile is. If the missile has, for instance, very high pressure inside its fuel tanks, and the laser is able to accurately point its beam on those tanks, then, because of the internal pressure, the missile might break up quickly once its outer skin is weakened by the laser. By contrast, if the laser must direct its energy on a missile that has a strengthened outer shell, is coated with reflective paint or lined with materials designed to absorb heat, or if the laser must aim at a missile stage that does not have such pressurized fuel tanks, then the lethal fluence required might be much greater. In addition, if the enemy missile is spinning, then any given spot on the missile will experience laser energy for only a fraction of the time, making it effectively harder.[15]

The effectiveness of the laser therefore depends crucially on the vulnerability of the threat it is attacking. To apply more energy, the laser would have to either be brighter (which is a function of the laser's power, the wavelength of the light, the diameter of the laser's mirror, and other factors) or be closer to the threatening missile. Given the design of the hydrogen fluoride laser that the Defense Department has proposed, the most straightforward way to increase its brightness would be to increase its output power, which in turn would likely make the laser larger and heavier. According to some analysts, the laser power needed to negate some enemy missiles already deployed could require a laser too massive to be lifted into orbit by the new booster discussed above. If the laser's brightness is not increased, then the range would have to be decreased, requiring more lasers in the constellation.

According to BMDO, a constellation of 12 to 20 satellites would be appropriate for addressing the threats of theater ballistic missiles, and a constellation of 24 satellites would be needed to defeat long-range ballistic missile threats to the United States. But other analysts argue that those constellation sizes are based on optimistic assumptions about the vulnerability of potential threats. Defending against one or more hardened missiles could require significantly larger constellations than the 24-satellite one that CBO assumes for its estimate. System costs would increase in direct proportion to the larger number of lasers composing the constellations.

Further uncertainty arises because other concepts for a SBL system are also under consideration. Those include combining space-based lasers with relay mirrors

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14. For example, suppose the lethal fluence required for a given enemy missile is 10 kj/cm^2. If that lethal fluence must be applied in no more than 100 seconds, then the minimum intensity would be 100 $watts/cm^2$, because one watt equals one joule per second.

15. For more on the physical principles behind space-based lasers, see Ashton B. Carter, *Directed Energy Missile Defense in Space: Background Paper* (prepared for the Office of Technology Assessment, April 1984).

also located in space and using advanced airborne or ground-based lasers in conjunction with a constellation of space-based relay mirrors.

Table 4 is a summary of CBO's cost estimates for the ground-based midcourse system, the stand-alone sea-based midcourse system, and the space-based

TABLE 4. SUMMARY OF NATIONAL MISSILE DEFENSE SYSTEMS AND COSTS

System Configuration	Possible IOC	Includes SBIRS-Low?	CBO's Cost Estimate (In billions of constant 2001 dollars)	Range of Annual Costs (In billions of constant 2001 dollars)
Ground-Based Midcourse Systems[a]				
Single-Site System with 100 Interceptors	2007	No	23 to 25	1 to 4
Two-Site System with 250 Interceptors	2010	Yes	51 to 58	2 to 7
Three-Site System with 375 Interceptors	2012	Yes	56 to 64	2 to 8
Stand-Alone Sea-Based Midcourse System[b]				
System Including Three Ships Patrolling Three Locations, Each Ship with 35 Missiles[c]	2010	Yes	43 to 55	2 to 7
Space-Based Laser System				
System with 24 Lasers in Orbit	2018	No	56 to 68	1 to 7

SOURCE: Congressional Budget Office.

NOTES: IOC = initial operational capability; SBIRS-Low = Space-Based Infrared System in low-earth orbit.

All ground-based midcourse and sea-based midcourse systems include one or more new X-band radars; upgrades of existing early-warning radars; and battle management, command, control, and communications centers.

a. Estimates for each ground-based system provide total costs, not incremental costs, and should not be added to one another.

b. The stand-alone sea-based midcourse system contains elements common to the ground-based systems. In addition, the patrol locations, velocity of the interceptors, and other key variables are based on its status as a stand-alone system. Therefore, the costs for it cannot be combined with those for a ground-based system.

c. The total number of ships needed to support three continuous patrol locations is seven or nine.

laser system. The remainder of this paper describes some of the technical characteristics of the two systems for which CBO did not estimate costs: a sea-based boost-phase system and the Brilliant Pebbles space-based interceptor system.

A Sea-Based Boost-Phase System

In concept, ships containing boost-phase interceptors could patrol near the coast of a specific potential adversary that might attempt to launch ballistic missiles against the United States. If a launch was detected, an interceptor missile would be launched from one of the patrolling ships and ram into the boosting enemy missile. Such a system would require a fast interceptor launched relatively close to its intended target.

Prior to this year, DoD was not actively pursuing or funding the development of sea-based boost-phase concepts. BMDO requested $685 million in fiscal year 2002 to explore boost-phase technologies, most of which was for the Airborne Laser program. Of the total request, $50 million was intended for sea-based boost-phase concept development, and the Congress appropriated $30 million for this purpose. Although many analysts believe that a sea-based boost-phase system is technologically feasible, it is still in the conceptual stage, and its specific requirements have not been described.

Ultimately, the costs and technical characteristics of a sea-based boost-phase system would depend on the number and location of the countries whose missiles it was designed to defeat. Targeting North Korean missiles from a ship might be easiest, given that country's small size and long coastline. On the other hand, Iran and Iraq are large countries with inland areas far from international waters. A sea-based boost-phase approach might be less practical for dealing with missiles launched from those countries. Because of the substantial uncertainties regarding technologies, configurations, and schedules, CBO was unable to develop a reasonable cost estimate for a sea-based boost-phase system. The following paragraphs discuss the factors that would most significantly affect the costs of such a system.

Interceptor Missiles. There are a number of different types of interceptors that might be developed for boost-phase missile defense on a ship. One possibility is that (as with the ground-based midcourse system) an interceptor could consist of a booster and a kinetic (hit-to-kill) kill vehicle. In that case, the booster would propel the kill vehicle at high speed toward the target, and the kill vehicle would separate from the booster and home in on the enemy missile. Another possibility is that the interceptor could carry an exploding, or blast fragmentation, warhead that might or might not separate from the booster that delivered it to the target. Any of those interceptor types would have to be capable of reaching a very high speed and doing so very quickly. According to a DoD official, prior missile programs have developed both of those capabilities but not in the same missile. The ultimate costs of a boost-phase interceptor would depend on its size and performance characteristics.

Ships. It is uncertain what type of ship would be needed for a sea-based boost-phase system. Because the interceptor in a boost-phase system must be very fast, it is also likely to be much larger than the Standard missile or Tomahawk missiles currently deployed aboard Navy surface ships. While the sea-based midcourse missile analyzed in the previous section would also be larger than existing missiles, a boost-phase missile could be still larger. Some analysts argue that, despite the potential size of this missile, existing cruisers could be modified to accommodate it; others believe that a large cargo ship would be sufficient; and still others believe that a new military ship would be needed.

Analysts also differ in answering the question of how many ships would be needed and whether or not they would be dedicated to the mission of national missile defense. If the boost-phase system could fit on an existing Navy cruiser, backfitting the cruisers with larger missile launch tubes or developing some alternative launch system would still be necessary. If existing cruisers could be backfitted for a boost-phase system, then, in theory, they might not be dedicated to that role. Rather, they might be called upon to deploy only when needed. Under that concept, the only costs the Navy would pay would be those for modifying launch systems to mount the larger missiles. If, however, existing cruisers were dedicated to the missile defense mission, then new Arleigh Burke DDG-51 destroyers might have to be purchased to replace them.

Sensors. The interceptor would likely be initially guided to its target by external sensors that would detect the enemy missile's launch and track its early trajectory. Existing Defense Support Program early-warning satellites could provide notice that a launch had occurred, but analysts differ about whether those satellites would be sufficient to allow the interceptor's kill vehicle to find the enemy missile. The Defense Support Program's planned replacement, Space-Based Infrared System High, would warn of the missile launch and might be adequate to track the enemy missile, but that process could take time, which could in turn affect the requirements of the booster and kill vehicle. In general, the more accurate the external tracking systems are, the less burden placed on the kill vehicle, which can then be smaller.

Other external sensors could be deployed, for instance, on the ground near potential launch sites, on an aircraft, on an unmanned aerial vehicle, or on the ship itself. Some analysts argue that such sensors could track the missile more accurately. If current Aegis cruisers were used as the boost-phase platform, then the Aegis SPY-1 radar might provide such sensor support, but that possibility remains to be explored. At extreme ranges, the Aegis radar may have insufficient capability.

Battle Management System and Operational Testing. Given the short time available for boost-phase intercept, parts of the battle management process might need to be automated, which could require that external sensors, ships' radars and launchers, and the kill vehicle itself all be part of a fully integrated system. The overall system would also have to undergo significant testing.

System Operation. The operating costs of a sea-based boost-phase system would depend on how many ships were involved and whether they were fully dedicated to the missile defense mission. For example, the total number of ships needed could be at least three or four for every single deployed ship (depending on where its home port and patrol areas were) because of the requirements for rotation and maintenance.

The range of possible elements reflects the uncertainty in the requirements, capabilities, and design of a sea-based boost-phase national missile defense system. Ongoing studies by both the Defense Department and outside analysts are expected to more completely explore the feasibility of and requirements for such a system.

The Brilliant Pebbles Space-Based Interceptor System

The Brilliant Pebbles system was planned to be capable of intercepting enemy missiles in the boost phase, just after boost, and in the midcourse phase. It was part of the first Bush Administration's missile defense architecture, known as Global Protection Against Limited Strikes, but was canceled in the early years of the Clinton Administration.

The system would consist of somewhere between 500 to 1,000 interceptors in orbit. Each interceptor would be housed in an orbiting satellite, called a "life jacket," which would protect the interceptor, maintain its orbit with small rocket motors, and communicate with ground stations. The life jackets would also carry sensors that would detect a missile launch. In the event of an enemy launch, the life jackets' sensors would detect and track the missile. Ground controllers would then evaluate the threat and, if appropriate, would authorize the system to make an intercept. The interceptors would then separate from the life jackets and travel at high speed toward the enemy missile. With their suite of on-board sensors, the interceptors would be highly autonomous. For boost-phase intercepts, external sensors would not be required, but for reliable intercepts in the midcourse phase, the system might require data from the SBIRS-Low satellites.

The technical and operational documentation for Brilliant Pebbles is almost a decade old. Consequently, CBO has no basis for developing a new estimate of the costs of Brilliant Pebbles, and CBO's previous estimates may no longer be applicable.[16]

The current Bush Administration plans to conduct research on space-based kinetic interceptors and to conduct a space-based test around 2005 or 2006. The Defense Department asked for $20 million in its 2002 budget request to pursue that research. The Congress appropriated $10 million for this effort in the 2002 defense appropriation bill.

16. See Congressional Budget Office, *Budgetary Implications of S.1635, The Defend America Act of 1996*, CBO Letter Attachment (May 1996).

APPENDIX:
ESTIMATES SHOWN IN CURRENT DOLLARS

TABLE A-1. COSTS IN CURRENT DOLLARS OF VARIOUS GROUND-BASED NATIONAL MISSILE DEFENSE SYSTEMS, FISCAL YEARS 2002-2015
(In billions of dollars)

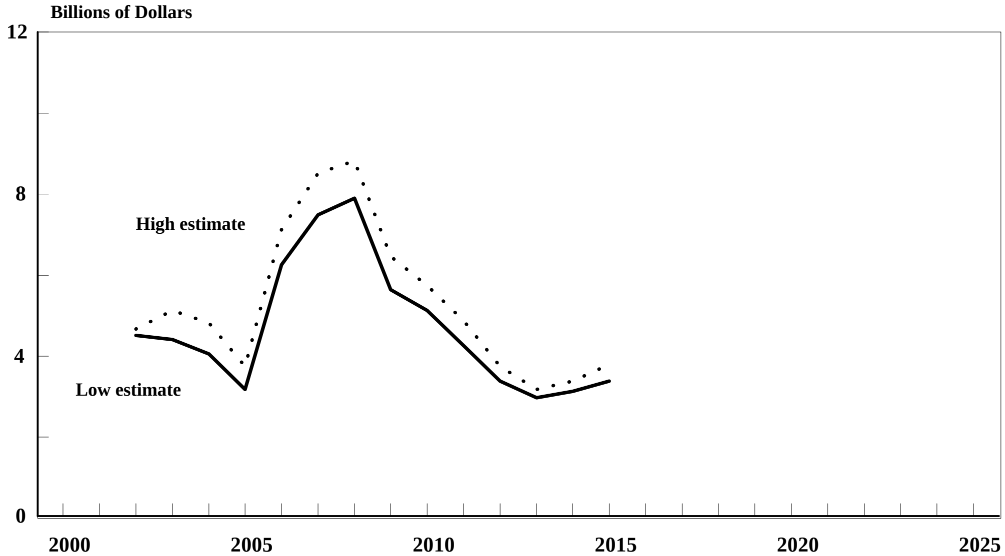
	A Single-Site System		A Two-Site System and More Radars/Sensors		A Three-Site System	
Type of Cost	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Research and Development						
Ground-based system	7	7	9	10	9	10
SBIRS-Low	0	0	4	6	4	6
Subtotal	7	7	13	16	13	16
Production						
Ground-based system	9	10	18	20	21	25
SBIRS-Low	0	0	10	13	10	13
Subtotal	9	10	28	33	32	38
Military Construction	1	1	3	3	5	5
Total Acquisition Costs	17	19	45	52	50	58
Operations Through 2015	9	9	15	15	16	16
Total Costs Through 2015	26	27	60	67	66	74
Memorandum:						
Prior Year Costs from 1996 to 2001	7	7	9	9	9	9

SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

SBIRS-Low = Space-Based Infrared System in low-earth orbit.

FIGURE A-1. ANNUAL COSTS IN CURRENT DOLLARS OF A GROUND-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM WITH THREE SITES, FISCAL YEARS 2002-2015



SOURCE: Congressional Budget Office.

NOTES: Total costs through 2015 = $66 billion to $74 billion.

The horizontal axis in this figure spans the period from 2002 to 2025. That time period would encompass the development, deployment, and initial operational testing of all of the missile defense systems for which CBO has made cost estimates.

TABLE A-2. COSTS IN CURRENT DOLLARS OF A STAND-ALONE SEA-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2015 (In billions of dollars)

Type of Cost	Total Costs: Low Estimate	Total Costs: High Estimate
Research and Development		
Sea-based system[a]	7	10
SBIRS-Low	4	6
Ships	*	*
Subtotal	11	16
Production		
Sea-based system[a]	12	15
SBIRS-Low	10	13
Ships	8	11
Subtotal	30	40
Military Construction	1	1
Total Acquisition Costs	43	57
Operations Through 2015	7	7
Total Costs Through 2015	50	64
Memorandum:		
Prior Year Costs from 1996 to 2001	9	9

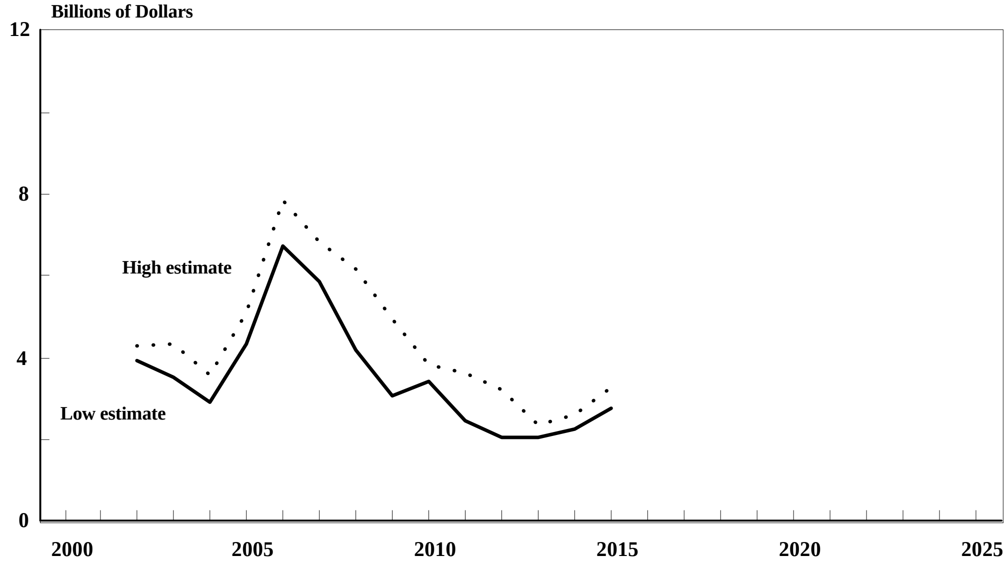
SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

SBIRS-Low = Space-Based Infrared System in low-earth orbit; * = about $500 million.

a. Includes the costs of sea-based interceptors and a ground-based infrastructure.

FIGURE A-2. ANNUAL COSTS IN CURRENT DOLLARS OF A STAND-ALONE SEA-BASED MIDCOURSE NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2015



SOURCE: Congressional Budget Office.

NOTES: Total costs through 2015 = $50 billion to $64 billion.

The horizontal axis in this figure spans the period from 2002 to 2025. That time period would encompass the development, deployment, and initial operational testing of all of the missile defense systems for which CBO has made cost estimates.

TABLE A-3. COSTS IN CURRENT DOLLARS OF A SPACE-BASED LASER NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2025
(In billions of dollars)

Type of Cost	Total Costs: Low Estimate	Total Costs: High Estimate
Research and Development		
IFX laser	4	6
Operational laser	9	14
Launch vehicle	4	6
Subtotal	17	26
Production		
Operational laser	41	50
Launch vehicle	21	21
Subtotal	62	71
Total Acquisition Costs	79	97
Operations Through 2025	3	3
Total Costs Through 2025	82	100

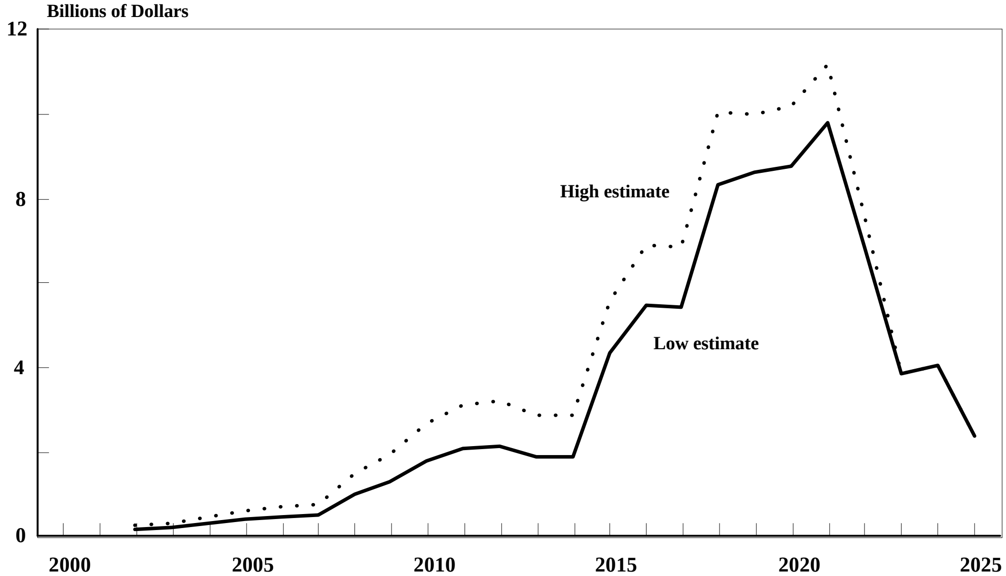
SOURCE: Congressional Budget Office.

NOTES: Numbers may not add up to totals because of rounding.

IFX = Integrated Flight Experiment.

The space-based laser (SBL) system comprises a constellation of 24 lasers.

FIGURE A-3. ANNUAL COSTS IN CURRENT DOLLARS OF A SPACE-BASED LASER NATIONAL MISSILE DEFENSE SYSTEM, FISCAL YEARS 2002-2025



SOURCE: Congressional Budget Office

NOTE: Total costs through 2025 = $82 billion to $100 billion.

Aegis: a combat system deployed on Ticonderoga class cruisers and Arleigh Burke class destroyers. Aegis is an integrated system for detecting threats and launching and guiding missiles to negate those threats. Its major components include the SPY1 radar, a command and control element, and launching and guidance elements for missiles.

Airborne laser: a missile defense system that would use 747 aircraft equipped with high-energy lasers to shoot down enemy missiles during their boost phase.

Ballistic missile: a missile that after a short powered flight coasts to its target (as opposed to a cruise missile).

Battle management: in national missile defense, battle management consists of analyzing incoming warheads and deciding on the appropriate response, such as how many interceptors to fire and when they should be launched.

Blast fragmentation: a method in which the interceptor's kill vehicle carries high explosives and is designed to destroy an enemy missile by exploding near to it. Blast fragmentation is in contrast to a hit-to-kill system, in which the kill vehicle destroys an enemy missile by ramming into it.

BMD: ballistic missile defense, intended to protect an area or country from ballistic missiles.

BMDO: Ballistic Missile Defense Organization, now the Missile Defense Agency.

Boost-phase system: a missile defense system designed to destroy an enemy missile during the initial period of flight when its rocket motors are firing.

Booster: the rocket stages that boost the kill vehicle into space.

Capability 2: the second stage of the Clinton Administration's national missile defense program. It would build on Expanded Capability 1 and was designed to cope with more-complex countermeasures. To achieve the increased capability, the system would add three more X-band radars at various sites around the world and more facilities to communicate with the interceptors while in flight. It would also add the Space-Based Infrared System satellites in low-earth orbit, known as SBIRS-Low. Those satellites would track the warheads as they glided through space and help the missile defense system distinguish the warheads from debris and countermeasures.

Capability 3: the final level of deployment for the Clinton Administration's national missile defense program. Capability 3 would include all of the assets of Capability 1 and Capability 2 and would add 150 deployed interceptors at a second interceptor site (possibly located in Grand Forks, North Dakota), more radars, additional communications facilities, and improved software for the systems' components.

Command and communications facilities: command centers (where commanders direct operations and control forces) and facilities to communicate with forces.

Constellation: a set of satellites (often identical or very similar) orbiting the earth to perform functions such as communications, global positioning, or early warning. The SBIRS-High system could consist of a constellation of five satellites, while the SBIRS-Low system could consist of 27 to 30. A space-based laser system might include 12, 20, 24, or even more satellites.

Countermeasures: measures taken by an attacker—for instance, using decoy warheads—to increase the likelihood that its warheads will get past defensive systems.

Cruise missile: a missile that remains under powered flight until it reaches its target (as opposed to a ballistic missile).

Defense Support Program (DSP): DSP satellites are the current U.S. early-warning satellites, based in geostationary (deep-space) orbit. Operating since the early 1970s, DSP satellites scan the earth's surface looking for the intense infrared light given off by missiles under powered flight.

Expanded Capability 1: the first stage of the Clinton Administration's plan for developing national missile defense. It was designed to defend the entire United States from attack by several tens of intercontinental ballistic missiles that employed simple countermeasures. The system would involve construction of a high-resolution X-band radar; battle management, command, control, and communications facilities; and an interceptor site (planned for Alaska) with 100 deployed interceptors. The system would also upgrade several existing early-warning radars and draw on the existing constellation of U.S. space-based early-warning satellites (the Defense Support Program, or DSP).

Flight tests: in the national missile defense program, flight tests are designed to test an individual component (such as the booster) or the entire system. The latter tests are known as integrated flight tests. To date, they have involved a target warhead launched from Vandenberg Air Force Base in California and an interceptor launched from Kwajalein Missile Range in the Marshall Islands. The flight paths of both of those devices were chosen so that they were in the downward portions of their trajectories when impact occurred, which prevented debris from being thrown into outer space and damaging satellites in orbit. That situation is considerably different from what an actual engagement would look like. The Bush Administration's planned test-bed facility in the Pacific is intended to provide more-realistic testing scenarios.

Hit to kill: a method in which the interceptor's kill vehicle destroys the incoming warhead by colliding with it, relying on the force of the impact and not on explosives.

IFX: Integrated Flight Experiment, a project of the Ballistic Missile Defense Organization (now the Missile Defense Agency) that will place a single subscale laser in space in order to test the concept of using space-based lasers to shoot down enemy missiles in the boost phase.

Intercontinental ballistic missile (ICBM): a land-based missile with a range of more than 3,000 nautical miles.

Interceptor: an interceptor consists of a kill vehicle and a booster to launch the kill vehicle toward the enemy missile.

Kill vehicle: in a hit-to-kill system, the component of an interceptor that is designed to collide with an incoming ballistic missile's warhead, destroying both by the force of the impact. The kill vehicle is released from its booster after leaving the atmosphere. For the ground-based national missile defense system, the kill vehicle contains an infrared camera, used to guide it to its target, and small rocket engines for maneuvering.

Low-earth orbit: an orbit about 500 to 2,000 kilometers above the earth (definitions vary on the precise altitude range). Satellites in the SBIRS-Low system might be launched into that orbit.

MDA: Missile Defense Agency.

Midcourse system: a missile defense system designed to destroy an enemy missile in the midcourse of its flight—after the rockets have stopped firing but before its warheads reenter the atmosphere.

National missile defense (NMD): systems that would protect the United States from an attack by intercontinental ballistic missiles.

SBIRS: the Space-Based Infrared System. SBIRS-High will consist of next-generation early-warning satellites in geostationary or highly elliptical orbits. SBIRS-Low will consist of satellites in low-earth orbit that are designed to track missiles under powered flight (when they are very bright if viewed in infrared light) as well as warheads that are gliding through space (which are much harder to observe).

System integration: the process of combining components (radars, missiles, communications systems, and so on) into an effective whole.

Theater missile defense: a defensive system designed to protect a relatively small area outside the United States, such as a battlefield, from attack by ballistic missiles with ranges of less than 1,500 nautical miles.

Tomahawk: a long-range cruise missile designed for land attack. It can be launched from Navy surface ships and from submarines.

VLS: vertical launch system, a missile launching system currently deployed on Aegis cruisers and destroyers. This system might be altered to house missiles larger than it can currently accommodate. Those larger missiles might be needed for a sea-based midcourse or sea-based boost-phase system.

X-band radar: a very high resolution radar that can, in principle, observe the shape and other characteristics of incoming objects as they glide through space. X-band radars are used for precision tracking and to help pick out a real warhead from any decoys or other benign objects that a missile may have released.